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Distribution of Benthonic Organisms and Hardness of Sea-bottom.

By

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(Transl. by Dr. Arata TERAO and Mituyo OKADA.)

(Received December 12th, 1928).

It is customary to describe the nature of sea-bottom as consisting of rock, sand, mud, or what not, and again to define sand, mud, etc. in terms of size of grains and relative proportion of grains of different sizes. But no attempt has been made to state hardness of an area of sea-bottom from a physical point of view. The present author has constructed a new device for measuring hardness of sea-bottom and done a series of experiments with it from June to July, 1927 in the eastern part of the Tateyama Bay, Prov. Bôshû, coupled with diving observations by himself.

The hardness was tested in the surface layer of sea-bottom, 30^{cm} in thickness, and its average value was read by the amount of force exerted in pushing a metal rod of a given bottom area of the new instrument, which I propose here to call "sea-bottom durometer," and the depth reached by the rod in the surface layer of the sea-bottom.

The "sea-bottom durometer" consists of a metal rod to be pushed into the soil and a frame holding it, as shown in Fig. 1. The metal rod consists of two parts, an upper (A) and a lower (B). The upper part has a ratchet and a scale engraved on the surface of the rod, and is loosely movable through a hole on the top of the frame when a claw-hook (C) is off the teeth of ratchet. The lower part is loosely movable through a hole at the centre of bed plate (Q) of the frame. A metal piece (M) attached to the end of the lower part (B) is changed with other pieces having different bottom-area according to the nature of sea-bottom. A sliding bar (SS) fixed to the lower end of the part

A of the rod moves on two pillars (P_1 and P_2) which are connected with the bed-plate. The frame, when in use, is hung from a boat by a rod (D) fixed to the lower extremity of a hoisting rope. The claw-hook is a **D**-shaped plate having a short projection bending upward on the curved margin of **D**, and is provided with a large hole in the central portion. This hole has on its one side a straight edge which fixes in a tooth of the ratchet. The plate is furnished with a leg which is pressed against the loose rod (D) by a spring. The claw-hook is let go from the loose rod (D) at a stroke of a messenger which fits in between the loose rod and the upper projection of the hook, and the claw-hook becomes off the tooth of the ratchet. The instrument is arranged, before using, with the rod (AB) pulled up so as to bring the surface of the lower extremity of the metal piece (M) in the same plane as the lower surface of the bed-plate. The spring (E) being compressed between the top of the frame and the sliding bar (SS) at the time of measurement, acts to push the rod into the soil as a consequence of unlatching of the claw-hook from the tooth of the ratchet. The loose rod is set up downward by a spring inserted between the top beam of the frame and the lower extremity of the rod. So, if the rope is pulled up, the loose rod, together with the messenger, is lifted up. The claw-hook becomes again inserted in a tooth, by means of which the rod is kept in such a position as the lower extremity of the metal piece (M) is pushed in.

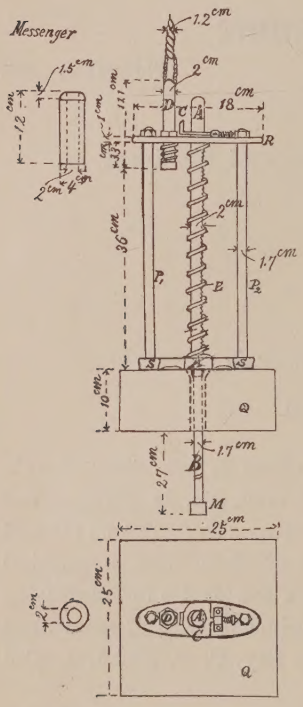

Fig. 1.

"sea-bottom durometer."

AB: metal rod to be driven into the soil; P_1P_2QR: frame; *SS:* sliding bar, attached to metal rod *AB*; *E:* spring to be compressed between the top of the frame, *R*, and sliding bar; *C:* claw-hook; *D:* loose metal rod.

The total weight of the durometer in air is 31.3 kg. The part A (the sliding bar inclusive) weighs 1.8 kg; the part B 0.9 kg., and the messenger 1.2 kg. The force which drives the rod into the soil is the sum of weights of the parts A and B and the elastic force of the spring (E). The relation between the reading of the durometer, l (in *cm*), *i.e.*, the distance which the metal rod AB travels on the elongation of the

spring (E) and the perforating force corresponding to l, f (in $kg.\ w.$), are given in Tab. I. The length l depends upon the bottom-area of the metal piece

TABLE I.

l^{cm}	f^{kg}	l^{cm}	f^{kg}	l^{cm}	f^{kg}
2	9.84	11	7.31	21	4.69
3	9.68	12	7.00	22	4.46
4	9.41	13	6.75	23	4.20
5	9.00	14	6.38	24	4.01
6	8.71	15	6.19	25	3.75
7	8.40	16	5.96	26	3.53
8	8.14	17	5.70	27	3.26
9	7.88	18	5.44	28	3.00
10	7.61	19	5.14	29	2.94
		20	4.95	30	1.96

(M). When we use a metal piece having small bottom-area at a place where the sea-bottom is too soft, the elongation becomes too great; on the other hand, when the bottom is too hard, the displacement of the metal rod becomes too small if it has too great bottom-area. In both cases, the reading does not represent the hardness correctly. Hence we must choose a metal piece of suitable bottom-area according to the hardness of the bottom.

In order to determine the relation between the quality and the hardness of bottom, the bottom is referred to nine classes according to the relative quantity of sand and mud. This ratio was measured in the following way. The writer himself dived in the sea and carried up about 15 kg. of the soil. Its total weight having been measured, the soil was washed up so as to take away the muddy element from it. The weight of the mud was measured and its ratio r, to the total weight, was calculated. The hardness and the value of r corresponding to each class of the bottom are shown in Tab. II. Metal pieces having bottom-area 4^{cm^2}, 9^{cm^2} and 16^{cm^2} respectively were used. Each of them was used for the bottoms having moderate hardness, and the results were compared. The durometer weighs 27 kg. in sea-water, and consequently the bed-plate is somewhat buried into the soil. The range of the sinking of the bed-plate, d^{cm}, was also measured.

From Tab. II it is seen that there exists a definite relation between r, and l, f, or d, so that we can infer with some degree of exactness the ratio

TABLE II.

Bottom / Bottom area of M	Class	1	2	3	4	5	6	7	8	9
	Ratio of mud.	0~0.2	0.2~0.3	0.3~0.4	0.4~0.5	0.5~0.6	0.6~0.7	0.7~0.8	0.9~0.9	0.9~1.0
$4cm^2$	l^{cm}	2~4	4~8	8~12	12~17	17~22	22~26			
	$f^{kg.W.}$	9.40~8.60	8.60~7.50	7.50~6.65	6.55~5.00	5.00~3.95	3.95~3.00			
$9cm^2$	l^{cm}		2~3	3~8	8~12	12~15	15~18	18~22	22~26	
	$f^{kg.W.}$		9.40~8.45	8.45~7.50	7.50~6.55	6.55~5.50	5.50~4.85	4.85~3.95	3.95~3.00	
$12cm^2$	l^{cm}			3~5	5~8	8~10	10~13	13~16	16~20	20~23
	$f^{kg.W.}$			9.00~8.25	8.25~7.50	7.50~6.95	6.95~6.30	6.35~5.45	5.45~4.85	4.85~4.10
Sinking of bed-plate, Q.	d^{cm}	1~2	2~3	3~4.5	4.5~6	6~7.5	7.5~9.0	9.0~11	11~12	12~13

of quantity of mud to that of sand from the measurement of the hardness.

Simultaneously with the measurement of the hardness of the eastern part of the Tateyama Bay as described above the writer repeated diving to observe the distribution of organisms, the turbidity of sea-water, *etc.* and also to measure the sinking distance of the bed-plate. But in so doing a measurement at a place which would not give true value of hardness of soil due to the presence of obstacles, such as fishes, shells, *etc.* was carefully avoided. Tab. II. contains the average values of hardness of the bottom as observed at all stations. These stations were settled by anchoring a boat at the bow and stern. The position of stations was determined by measuring with a sextant two angles between three points on the shore and it was marked on a chart with a station pointer. Fig. 2. shows the result of the survey.

The organisms were collected from the stations by trawling and also were observed *in situ* by diving. To find out food material of bottom-feeders about one kg. of soil was collected with a fine-meshed bug-net (mojiami) at all stations and sandy or muddy element was washed out from the soil. Tab. III lists these organisms arranged according to 9 classes of the bottom at the stations where they were found. From Table III we see that a close relation exists between the distribution of various organisms and the nature of the bottom. Where the bottom is very hard, *viz.*, referrable to the classes (1) and (2), I found several fishes which are venomous, such as *Dasybatus akajei* (Müller & Henle), or *Hypodytes rubripinnis* (Temminck & Schlegel) or ferocious, such as

Oxystomus macrorhynchus Bleeker, or those having protective colour such as *Phinoplagusia japonica* (Temminck & Schlegel). Those crustaceans and fishes

Fig. 2.

which burrow in the upper layers of the sea-bottom, such as *Limanda angustirostris* Kitahara, *Pseudoblennius percoides* Günther, *Astroconger myriaster* (Brevoort) or *Muraenesox cinereus* (Forskål), are mostly found where the bottom is moderately hard, *i. e.*, of classes (4), (5) and (6). The larvae of most fishes are found in turbid water, *viz.*, where the bottom is very soft, and some migrating fishes which feed on those larvae are also found there. The larvae of *Pagrosomus major* (Temminck & Schlegel) live in the bushes of *Zostera marina* L. which grow on the hard bottom of class (1). But *Pagrosomus*

changes its habitat as it grows up, and the fry of about 7^{cm} in length were found on the bottom of class (5), those of about 4^{cm} in the classes (3) and (4), and those having about 10^{cm} in length in the class (8) or (9). Consequently we see that the newly hatched larva of *Pagrosomus major* (T. & S.) takes plankton as food, a little older one lives on minute crustacea, annulata, etc. and the fry of about 10^{cm} in length feed on young *Sardinia melanostieta* (T. & S.) at the sea-bottom where water is turbid.

In conclusion, the writer expresses his best thanks to Mr. Hidetosi Kusama and Mr. Matutarô Kobayasi for thier kind helps rendered to him during the surveying.

Summary.

1. By the newly designed "sea-bottom durometer" the hardness of the upper layer of sea-bottom was measured and a simple relation was obtained between the hardness of the bottom and the ratio of mixing of sand and mud.

2. Close relations between the distribution of some 60 species of benthonic organisms and the nature of sea-bottom was observed.

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	Chloeia flava (Pallas).					+	+	+	
Prosopygii.	*Phascolosoma japonicum* Ikeda.				+	+			
Mollusca	*Meretrix meretrix* Linné.	+	++						
	Rapana thomasiana Grosse.	+	+						
	Mactra veneriformis Reeve.		+						
	Pecten laquaetus Sowerby.		+	+					
	Pecten (Patinopecren) yessoensis Jay.			+					
	Paphia philippinarum Adams & Reeve.		+	+	+				
	Ostrea (Crassostrea) gigas Thunberg.		+	+	+				
	Atrina japonica lischkeana Cless.			+	++	++			
	Schizothaerus nuttalli Conrad.				+	+			
	Atrina japonica Reeve.				+	+	+		
	Pinctada martensi Dunker.				+	+	++	+	
	Latrunculus japonicus Sowerby.						+	+	
	Novaculina constricta Cless.							+	+	++
	Sepia esculenta Hoyle (smaller).							+		
	„ „ „ (bigger).								+	+
Arthropoda	*Balanus sp.*	+	+	+	+	+				
	Pagurus sp.	+	+	+						
	Squilla oratoria de Haan.		+	+						
	Alpheus brevicristatus de Haan.		+	+	+					
	Penaeopsis monoceros (Fabricius).				+					
	Portunus trituberculatus (Miers).				+	+	+			
	Uca arcuata (de Haan).					+				
	Penaeus japonicus (Bate) (Small).				+	+	++			
	„ „ „ (big.)						+	+		
	Trigonoplax unguiformis (de Haan).						+	+		
	Latreilla phalangium de Haan.								+	+
Pisces	*Pterois lunulata* Temminck & Schlegel.	+	+							
	Phinoplagusia japonica (T. & S.)	+	+							
	Oxystomus macrorhynchus Bleeker.	+	+							
	Halichoeres poecilopterus.	+	+	+						
	Astroconger myriaster (Brevoort).	+	+	+						
	Nibea mitsukurii (Gordan & Snyder).				+	+	+			
	Muraenesox cinereus (Forskål).					+	+			
	Pseudoblennius percoides Günther.				+	+	+	+		
	Dactyloptena orientalis (Cuvier & Valenciennes).					+	+	+		
	Anago anago (Temminck & Schlegel).							+	+	
	Platycephalus indicus (Linnaeus).		+	+						
	„ „ „				+					
	Limanda angustirostris Kitahara.		+	+						
	„ „ „ (bigger).				+	+	+			
	Sparus macrocephalus (Basilewsky).		+	+						
	„ „ „ (bigger).				+	+				
	„ „ „ (biggest).									
	Pagrosomus major (T. & S.) (Larva).	+	+							
	Pagrosomus major „ (young, small).			+	+					
	„ „ „ „ „ bigger).					+				
	„ „ „ („ „ biggest).							+	+	+
	„ „ „ (old, smaller).					+	+			
	„ „ „ („ „ bigger).							+	+	
	Sardinia melanosticta (T. & S.) (Larva).									+
	Some migrating fishes.									+

On the Biology and Culture of the Marine Alga, *Porphyra tenella* Kjellm. (*Asakusanori*).

By

Daijiro KUSAKABE.

(Received September 16th, 1929).

The life-history of the marine alga, *Porphyra tenella*, has of late been much elucidated from the pen of Ueda[1]; and yet our knowledge of the same is far from satisfactory. The present paper embodies my own observations on the same with special reference to its culture from an economic point of view.

It is my pleasant duty to return herewith my sincerest thanks to Professor Okamura for his kind guidance during the course of my study. I fully appreciate the benefit of discussion of the problem with Professor Tauti, Mr. Ueda, and Mr. Hori. I am also much indebted to Professor Terao for assistance in preparing the manuscript.

Our search in autumn for the spore of this alga brought out the fact that this plant propagates during this season by producing exclusively monospores which are spherical, 12—17 μ in diameter, naked or covered by a very thin structureless membrane, provided with a single, central, faintly reddish brown chromatophore. These monospores are set free from the frond of *Porphyra* which has germinated from the carpospore found late in spring.

This monospore soon gives rise to a young plant which is capable of producing monospores which again germinate at once. Such a cycle of reproduction is repeated twice or thrice during colder season. It has long since been known to fishermen that young fronds of *Porphyra tenella* are found three times during colder seasons, viz., "winter solstice young," "cold season young," and "out-of-season young" as called by fishermen. Our studies on this point furnish this with a scientific explanation.

The young plant which has germinated from the carpospore in spring sustains its existence on the old collecter erected off shore, and can bear any sudden change of temperature and salinity.

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(1) Ueda S.:—On the life history of Porphyra tenella kjellm. (Journ. Imp. Fish. Inst. Vol. XXIV, No. 5 March 1929).

When injured, it resorts at any time to the production of monospore by which it attains the maintenance of the species as such. There exists a remarkable lunar periodicity in the liberation of monospores: they are liberated at flood of spring tides. Their first liberation in autumn is also related to a drop of mean air temperature a day to about 20°C. Consequently we can predict the time for liberation of such and such year by reading thermometer and referring to the tide-table.

The detritus seems to play a rôle for the attachment and germination of the plant upon the collecter, since it makes the surface of the collecter rougher and supplies a good hold for the alga.

The exposure of the collecter to air is essential for the culture of the marine alga in question in the sense that such exposure destroys infusorians interfering with attachment of germinating spores to the collecter.

The experience thus far recorded had led me to construct a quite original design which was registered as utility model No. 131583 by the Bureau of Patent of the Japanese government. This design consists of hanging collecters from the supporters. This facilitates the gathering of the alga from the collecter irrespective of bad conditions of the sea. It has another advantage in the ease to remove to any place where the current brings much nutrition to the alga.

Nuptial Organ of the Salmonoid Fish, *Plecoglossus altivelis* T. & S.[1]

By

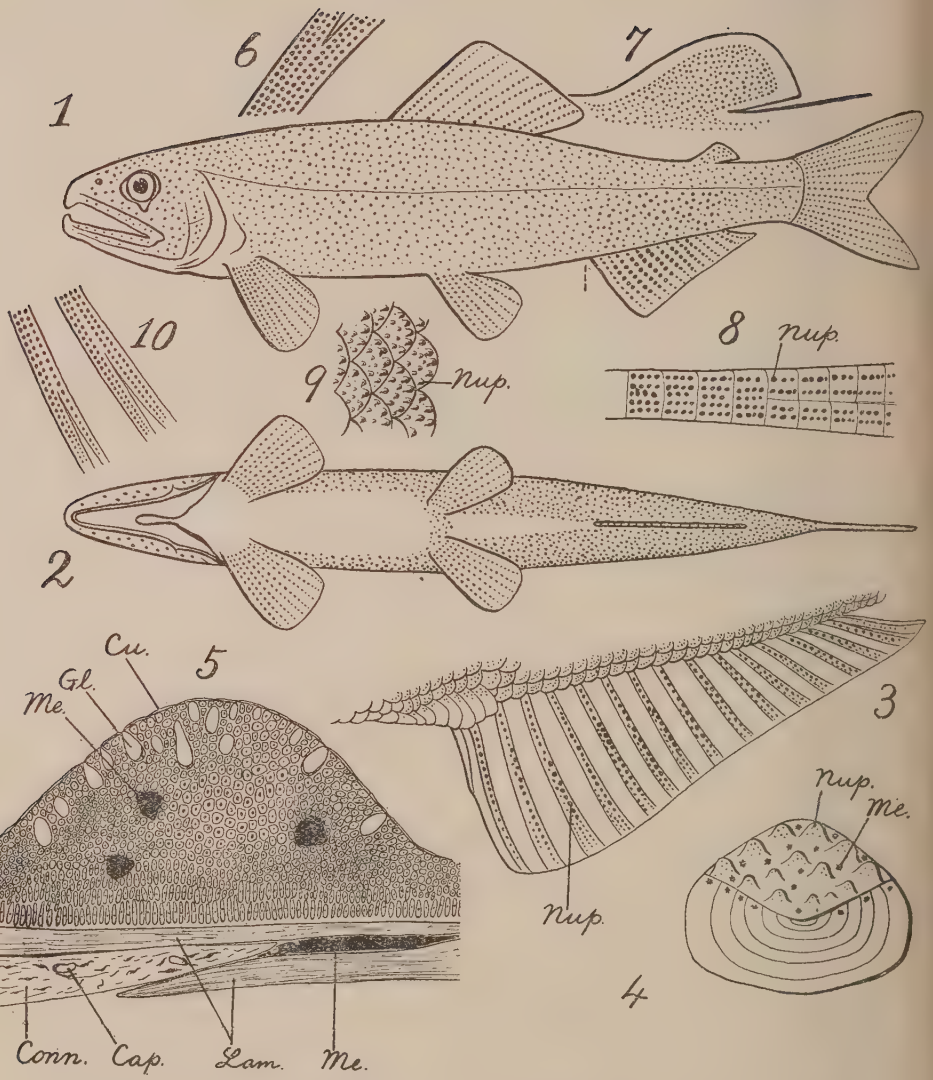
Ken-ich EBINA.

(Received October 28th, 1929).

Economically very important as it is in Japan, the spawning male of the salmonoid fish, *Plecoglossus altivelis* T. & S., has not yet been described as having numerous minute integumentary protuberances which I propose to call "nuptial organs." The organs do not occur in the female at all; neither is the case with young males. So far as my observations go, the period for producing the organs in question seems to last from October to November, one maximum for their development occurring in November.

The organs cover almost the entire body surface of the adult male during breeding season, viz., head, gill cover, scales, adipose fin, and rays of all the other fins (Fig. 1). But snout end, opercular membrane, and a narrow stripe on the ventral surface from the jugular portion to the anus with an interruption, between the ventral fins, of several scale rows furnished with the nuptial organs are destitute of the protuberances (Fig. 2). They are found rather sparingly on the head and gill cover, but much crowded on the scales, numbering 10—15 on each (Figs. 4 and 9), and also on the fin rays where they form 1—6 rows (Figs. 3, 6, 8, and 10). Their size is almost uniformly small on the adipose fin (Fig. 7) and scales (Fig. 3), but it varies greatly in other regions. The largest ones are situated on the rays in the middle part of the anal fin, reaching $0.6^{m.m.}$ in diameter in a speciemen measuring $23.^{c.m.}$ in length. Externally observed, they represent conical, round-topped protuberances with axes sometimes a little inclined posteriorly (Fig. 9.), and are more or less of a whitish colour in formalin specimens. The melanophores which are found abundantly all over the body-surface of the male to make

(1) Contributions from the Zoological Laboratory (Director: Professor A. Terao), Imperial Fisheries Institute, No. 3. The preceding two are: No. 1. A. Terao, Relative rate of reproduction as a phase of population growth of organism; No. 2. A. Terao and T. Tanaka, Anaesthesia of the water-flea, *Moina macrocopa* Straus, in relation to age.



1. Side view, stippled area representing the region covered with nuptial organs (×1.8).
2. Ventral view, stippled area being the same as in Fig. 1.
3. Anal fin (×1.33)
4. Scale (×16.6)
5. Median section through the nuptial organ on scale (×211)
6. A dorsal fin-ray (×4)
7. Adipose fin (×1.4)
8. An anal fin-ray (×8)
9. Several scales above the anal fin (×4.3)
10. Two pectoral fin-rays (×6.6)

Cap., blood-capillary;
Gl., unicellular gland;
Me., melanophore;
Conn., connective tissue;
Lam., scale lamella;
Nup. nuptial organ.

up the characteristic male nuptial colouration are also seen within these protuberances as smaller black dots.

In section[1], the outermost layer of the body in question is found forming a very thin cuticular layer whose cellular nature is much obliterrated. This layer is perforated by the openings of very large unicellular glands (Fig. 5, *Gl.*) which are more abundant near the top but less toward the periphery. Beneath the cuticular layer are present either flattened or polygonal cells constituting several compact layers which pass into a central cellular mass. The central mass is composed of much swollen cells measuring about twice as large in diameter as those in the corresponding part of the ordinary integument over the scale. The cell in this part is also characterized by the presence of a vesicular nucleus within it and wide spaces arround it. Fibrillar strands traverse these intercellular lumina connecting the cells together. The basal layer is composed of mostly cylindrical, but sometimes polygonal, cells which are separated from the underlying tissues by basement membrane. The melanophores are mostly found near the central mass of the organ.

It is clear from the foregoing description that the organ of my material differs from the pearl organ in lacking the cornified layer which gives the organ in the cyprinoid fishes[2] the pearl-like appearance and such designation. The nuptial organ of *Plecoglossus* is also distinguished from the contact organ on the scales of killifishes[3] by the absence of bony support within it. It may be mentioned that both the male and female of the present species come close together and touch with each other side by side during spawning act but no hugging is observed as is the case with the killifishes, thus the nuptial organ of my material not appearing to serve so much for contact. With a view to avoiding the possibility of naming in future similar but a little different organs by new terms I would like to name the pearl organ, contact organ and the like by the general term "nuptial organs" whose definition runs as follows:—

"*The nuptial organ is an integumentary structure or structures occurring in fishes during breeding season, either characteristic to male or common in both sexes, and often related at varying degrees with the nuptial colouration.*"

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(1) I am much indebeted to my colleague Mr. Tomozô Tanaka for assistance in preparing the slides.

(2) Meisenheimer, J. Geschlecht und Geschlechter im Tierreich, 1921. Tozawa, T. Studies on the pearl organ of the goldfish. Annot. Zool. Japan Vol. 10, 1923.

(3) Newman H. H. Contact organ in the killifishes of Woods Hole. Biological Bulletin Vol. 17, 1909.

Studies of Netting Cords IV.
Strength of Cord in Relation to the Twist.

By

Dr. M. Tauti.

(Received October 9th, 1929).

Kawai[1] stated that the cotton cord is strong when the upper and lower twists* are in equilibrium, especially when the both twists are in suitable numbers. And he referred this fact to the minimum bend of fibres. Kawai and Dr. Terada[2] confirmed that, as to the cord the thread of which is composed of less than 60 yarns, the strength varies directly as the weight per unit length irrespective of the tightness of the twist, and that the strength varies directly as the number of yarns composing the cord. They explained these facts by the following two assumptions: (i) the strength of a cord varies as the total sectional area of fibres in cross section of cord; (ii) the slope of fibre is same** irrespective of the tightness of twist and the size of cord. Matthews[3] pointed out that "single yarns will give only about 20 percent of the breaking strain calculated from the strength of the separate fibres; two-ply yarns give about 25 percent."

If all the fibres composing a yarn can be taken quite equally, each of them may be assumed to support an equal portion of external load applied to the yarn. Then the fact pointed out by Matthews seems to suggest that the breaking of yarns should be resulted from the slipping of fibres which takes place when the external load reaches the total frictional force between fibres, but not from the breaking of all the fibres in cross section of yarns. The fact that the two-ply yarn is somewhat stronger than the single yarn of the same count can be understood to rise from the fact that, in a two-ply yarn loaded the frictional force between fibres is greater than in a single yarn,

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(1) K. Kawai, J. Imper. Fish. Inst., VI, 3 (1910).

* For the meaning of "upper and lower twists" the reader should refer to the lines in Italics on pp. 30–31.

(2) K. Kawai and T. Terada, J. Imper. Fish. Inst., IX, 6 (1914).

** Accordingly the sectional area of fibre in cross section of cord is same.

(3) J. M. Matthews: Textile Fibers, 4 Ed. (New York, 1924), 447.

according to one thread being compressed by the other. The same idea for mechanism of breaking can, of course, be applied to the case of a cord. Thus the breaking strength of a cord must increase with the compressive force due to load applied to the cord, but it can not exceed 50 percent of the product of the breaking strength of separate fibre and the number of fibres in cross section of the cord, as known from the following calculation:—Express the frictional force per unit length of a fibre by f and the length of a fibre by λ, then the load supported by a fibre, which is divided by the plane of any cross section of cord into two portions in the length of $\lambda-x$ and x, is fx when $x \leqq \frac{\lambda}{2}$. So, if the total number of fibres in the cross section be F and the load sustained by the cord that is the breaking strength be L,

$$L=\int_0^{\frac{\lambda}{2}} 2kfx\,dx \quad \text{and} \quad F=\int_0^{\frac{\lambda}{2}} 2k\,dx,$$

because the strength of a cord is equal to the sum of the frictional force acting on fibres in cross section of the cord.

Then
$$\frac{L}{F}=\frac{kf\left(\frac{\lambda}{2}\right)^2}{2k\left(\frac{\lambda}{2}\right)}=f\frac{\lambda}{4}$$

But the frictional force acting on the half length of a fibre cannot exceed the breaking strength of the fibre, τ.

Then
$$f\frac{\lambda}{2} \leqq \tau$$

Hence
$$\frac{L}{F} \leqq \frac{\tau}{2} \quad \text{or} \quad L \leqq \frac{\tau F}{2}$$

Now express the breaking strength of a yarn by w_0 and the increase of the total frictional force on fibres that is the increase of the breaking strength of the yarn by μP when the pressure P is applied laterally on the yarn, then the load sustained by a p-ply cord, of which each of p threads is composed of those ν yarns, is equal to $p\nu(w_0+\mu P)$, if the pressure between the yarns is P. *When a bundle of ν yarns put in parallel is twisted N times per meter and again a bundle of p threads thus prepared is twisted n times per one meter of the original length of yarns, i.e. when the lower twist is N and the upper*

twist is n, the resulting twist of thread is $N-n$. It was shown in my previous papers[1] that any one of the ν yarns can be assumed to coil around the other $\nu-1$ yarns, in a form somewhat like common-helix. As the curvature of the yarn is $\frac{4\pi^2 r'}{\left(\frac{1000}{N-n}\right)^2}$ putting the radius of the helix r', P is nearly equal to $\frac{W}{p\nu\cos\alpha}\frac{4\pi^2 r'}{\left(\frac{1000}{N-n}\right)^2}\frac{1}{\sqrt{\pi}\rho}$, where W is the load applied to the cord, ρ is the radius of the yarn, and α is the angle between the yarn and the centre line of the cord. The pressure applied on one thread by the others should not be neglected when n is large in comparison with $N-n$, but otherwise, the cord breaks when the load shared to each yarn, $\frac{W}{p\nu\cos\alpha}$, is equal to the breaking strength of the yarn, $w_0+\mu P$. Accordingly the breaking strength of cord in relation to the twists is given by the next equation (1).

$$\frac{W}{p\nu\cos\alpha}=w_0+\mu\frac{W}{p\nu\cos\alpha}\frac{4\pi^2 r'}{\left(\frac{1000}{N-n}\right)^2}\frac{1}{\sqrt{\pi}\rho},$$

or

$$\frac{W}{p\nu\cos\alpha}=\frac{w_0}{1-\frac{4\pi^2\mu}{\sqrt{\pi}\rho}\times 10^{-6}r'(N-n)^2} \quad \text{.....(1)}$$

α and r' may be calculated by the following equations:

$$\sin\alpha=\frac{2\pi r'}{\left(\frac{1000}{N-n}\right)} \quad \text{and} \quad r'=r\sqrt{\frac{\nu-1}{\nu}},$$

where r is the radius of thread when the cord is just to break down, but in the approximate calculation, the radius of thread tightly twisted may be substituted for r.

To verify the relation above stated, the author troubled Mr. H. Muta to measure the lower twist, N, the upper twist, n, the length of cord made of bundle of yarns one meter long, $1-S$, the breaking strength of cord, W,

(1) M. Tauti, J. Imper. Fish. Inst., **XXII**, 4 (1927) and **XXIII**, 3 (1927).

and the radius of thread, r, in the case when the upper and lower twists are nearly in equilibrium. The result obtained, and the calculated values of r', $\frac{2\pi r'}{\left(\frac{1000}{N-n}\right)}$, $r'\ (N-n)^2\times 10^{-6}$ and $\frac{p\nu\cos\alpha}{W}$ are given in Table I. The average values of $\frac{p\nu\cos\alpha}{W}$ and $r'(N-n)^2\times 10^{-6}$ are calculated from Table I for each of several groups classified according to the magnitude of $r'(N-n)^2\times 10^{-6}$ and the values are arranged in Table II. Fig. 1 shows graphically the relation between those average values. From this figure

Table II.

Cotton cord.

Sense of the upper twist	Average value of	$r'(N-n)^2\times 10^{-4}$					
		0—.20	.21—.50	.51—1.00	1.01—2.0	2.1—5.0	5.1—
3-ply *left*	$r'(N-n)^2\times 10^{-4}$	.12	.36	.71	1.41	3.2	7.8
	$\frac{p\nu\cos\alpha}{W}$	3.1	2.6	2.5	2.3	2.0	2.0
3-ply *right*	$r'(N-n)^2\times 10^{-4}$	.13	.33	.78	1.47	2.9	
	$\frac{p\nu\cos\alpha}{W}$	2.5	2.3	2.2	2.1	1.9	
2-ply *left*	$r'(N-n)^2\times 10^{-4}$	.10	.32	.70	1.44	3.2	
	$\frac{p\nu\cos\alpha}{W}$	2.8	2.7	2.4	2.2	2.1	
2-ply *right*	$r'(N-n)^2\times 10^{-4}$	.10	.32	.73	1.63	3.1	
	$\frac{p\nu\cos\alpha}{W}$	3.0	3.0	2.6	2.7	2.4	

Ramie cord.

Sense of the upper twist	Average value of	$r'(N-n)^2\times 10^{-4}$				
		0—.10	.11—.20	.21—.50	.51—1.00	1.01—
2-ply *left*	$r'(N-n)^2\times 10^{-4}$	.07	.14	.35	.66	1.57
	$\frac{p\nu\cos\alpha}{W}$	.69	.55	.49	.44	.36
2-ply *right*	$r'(N-n)^2\times 10^{-4}$	.07	.16	.37	.73	1.22
	$\frac{p\nu\cos\alpha}{W}$	.90	.62	.45	.41	.38

we learn that the above-stated relation of the breaking strength of cord to the twist holds good for 2- and 3-ply cotton (and ramie) cords having

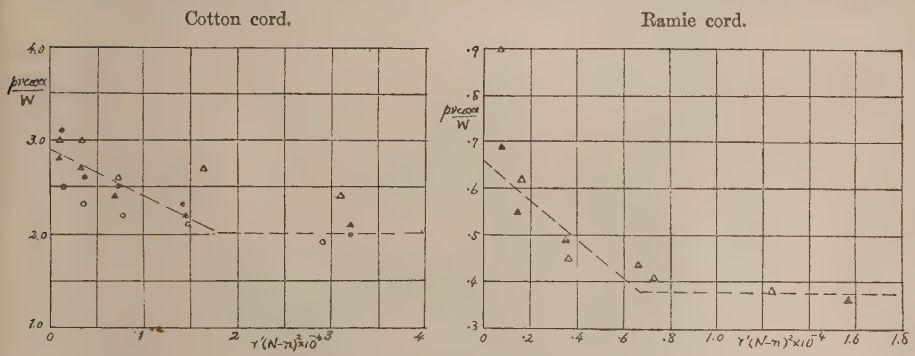

Fig. 1.

●...3-ply *left*, ○...3-ply *right*, ▲...2-ply *left*, △...2-ply *right*.

the right- or left-handed upper twist, excepting very loose right-handed one. $\left(\frac{p\nu\cos\alpha}{W}\right)_0$, $\left(\frac{p\nu\cos\alpha}{W}\right)_{\text{min.}}$ and $\frac{4\pi^2\mu}{\sqrt{\pi\, w_0\rho}}$ are obtained from Fig. 1. The original strength of yarn, w_0, the maximum load sustained by the yarn, $w_{\max}$, and the coefficient of friction of yarn, μ, are calculated from the values as obtained above, substituting $\frac{r}{\sqrt{\nu}}$ in the case of the tight twist for ρ, as shown in Table III.

TABLE III.

	$\left(\frac{p\nu\cos\alpha}{W}\right)=\frac{1}{w_0}$	$\left(\frac{p\nu\cos\alpha}{W}\right)_{\text{min}}=\frac{1}{w_{\max}}$	$\frac{4\pi^2\mu}{\sqrt{\pi\, w_0\rho}}$	$\rho=\frac{r}{\sqrt{\nu}}$
Cotton	2.9	2.0	0.50×10^2	0.11
Ramie	0.66	0.38	0.41×10^2	0.33
	w_0	$w_{\max}$	μ	$\frac{w_{\max}}{w_0}$
Cotton	0.34	0.50	0.086	1.45
Ramie	1.52	2.62	0.90	1.72

A yarn cannot give the strength more than 50 percent of the breaking strain calculated from the strength of the separate fibres and the mean strength, 280 gr, of a 20′s single cotton yarn is 20 percent of that breaking strain, so the yarn cannot sustain a load over 700 gr. Accordingly the upper limit of

the breaking strength of a cord composed of 20's cotton yarns $p\nu$ in number, should be somewhat less than 0.7 $p\nu$ kg., because the load applied on a cord may be more or less unequally shared to each yarn. This maximum value is 0.5 $p\nu$ kg. as seen in Table III.

If the coefficient of friction per unit area of fibre be expressed by μ_0, the length of fibre by λ and the diameter by δ, and the number of fibres in cross section of yarn by $\varkappa$, then $\mu \propto \varkappa \mu_0 \lambda \delta$ approximately. And for 20's cotton yarn $\lambda \fallingdotseq 1''$, $\delta \fallingdotseq \frac{0.76}{1000}''$, $\varkappa \fallingdotseq 200$ and for ramie $\lambda \fallingdotseq 5''$, $\delta \fallingdotseq \frac{2}{1000}''$, $\varkappa \fallingdotseq 170$. Then, neglecting the difference between μ_0 for cotton and μ_0 for ramie, the ratio of μ for ramie to μ for cotton should be equal to $\frac{170}{200} \times \frac{5}{1} \times \frac{2}{0.76}$ or 11, which coincides with the value of this ratio calculated from Table III.

Soft cords having the right-handed upper twist do not satisfy the equation (1), as n is large in comparison with $N-n$, but in this case the relation of the breaking strength to the twist may be expressed by the equation in which n is substituted for $N-n$ in the equation (1), putting

$$\sin \alpha = \frac{2\pi r'}{\left(\frac{1000}{n}\right)} \text{ and } r' = \text{radius of cord} \times \sqrt{\frac{p\nu - 1}{p\nu}}.$$

A cord, of which the upper and lower twists are in equilibrium, may be regarded as a homogeneous elastic body, because it is not twisted in any direction whatever, whereas a cord, of which the upper or lower twist is in excess, may be regarded as one twisted as much as the extra twist in its direction. So, yarns or elements of the cord are strained corresponding to the extra twist, when it is prevented from untwisting. Hence in case the upper and lower twists are not in equilibrium, the external load which can be supported by each yarn of the cord should diminish as much as the tension due to the extra twist. Accordingly the breaking strength of cords decreases as the extra twist increases, the difference between the upper and lower twists remaining the same.

Miyake[1] made an experiment on the breaking strength of cotton cords related to the twist in a wide range covering also the case not in equilibrium.

(1) Y. Miyake made this experiment under the guidance of the author.

Fig. 2 shows his results on 3-ply cotton cords which have the left-handed upper twist and each thread of which is composed of 6 20′s yarns.

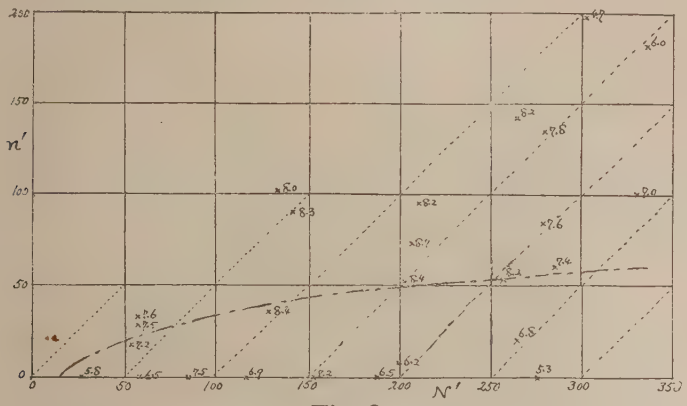

Fig. 2.

Numerals in this figure represent the breaking strength of cord
n'...Number of upper twist in 30cm of cord.
N'... „ „ lower „ „ „ „ „
———— ... Equilibrium condition of twists.

As 20′s cotton yarns used are twisted left-handedly about 1000 per meter; ramie yarns 320 per meter in the same sense, they have a tendency to untwist in free state. So when ν yarns are put in parallel and tied up in a bundle at both ends, this bundle must be twisted in the right-handed sense until the resultant of two couples, one of which is required to keep the yarns in resulting twist and the other to keep them in resulting bend, has a direction perpendicular to the centre line of the bundle.

Now express the former couple by c, the latter by c' and the angle included between each yarn and the centre line of the bundle by θ (See Fig. 3), then

$$\frac{c}{c'} = \tan\theta$$

But, putting the number of twists of the bundle N, the radius of yarn ρ, and the radius of helix constructed by each yarn r',

$$c' \propto \rho^4 \frac{r'}{\left(\frac{1000}{N}\right)^2} \quad \text{and} \quad \tan\theta = \frac{2\pi r'}{\sqrt{\left(\frac{1000}{N}\right)^2 - 4\pi^2 r'^2}}$$

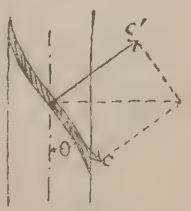

Fig. 3.

Hence $$c \propto \frac{2\pi r'}{\sqrt{\left(\frac{1000}{\underline{N}}\right)^2 - 4\pi^2 r'^2}} \cdot \rho^4 \frac{r'}{\left(\frac{1000}{\underline{N}}\right)^2},$$

or $$c \propto \nu \underline{N}^3,$$

because $r' \fallingdotseq r \propto \sqrt{\nu}$ and $\frac{1000}{\underline{N}} >>> 2\pi r'$

Table IV gives the values of $\underline{N}$ measured in cotton and ramie yarns used in the present study, as well as the calculated values of $\nu^{\frac{1}{3}}\,\underline{N}$.

TABLE IV.

	20's Cotton yarn							
ν	4	6	8	12	20	30	40	60
$\underline{N}$	57	54	52	43	40	31	29	23
$\sqrt[3]{\underline{N}}$	90	98	104	95	109	96	99	90
	Ramie yarn							
ν	4	8	12	20	30	60	100	
$\underline{N}$	21	20	19	17	15	9	7	
$\sqrt[3]{\underline{N}}$	33	40	43	46	47	35	33	

Next, twist a bundle of ν yarns put in parallel N times per meter and again twist a bundle of two or three threads thus prepared n times per one meter of the original length of yarns in the opposite sense, then the resulting twist of these threads is $N-n$ and the couple required to maintain the resulting twist of each thread is proportional to $r^4 s\ (N-n \mp \underline{N})$, where s is the rigidity of the thread, r is the radius and the sign + (or −) must be taken in case the lower twist has the same (or opposite) sense as that of yarns. As the curvature of each thread due to the upper twist, n, is nearly equal to $\frac{4\pi^2 ar}{\left(\frac{1000}{n}\right)^2}$ (in this expression ar being the radius of helix constructed by the centre line of the thread) then the couple required to keep the bend of thread is proportional to $r^4 E \frac{4\pi^2 ar}{\left(\frac{1000}{n}\right)^2}$, where E is Young's modulus of thread. The upper and lower twists can be in equilibium when the resultant of these two couples is perpendicular to the centre line of cord thus prepared. Hence the following equation holds between N and n when the twists are in equilibrium.

$$\frac{\frac{2\pi ar}{1000(1-S)}}{n} \propto \frac{r^4 s(N-n\mp\underline{N})}{r^4 E\frac{4\pi^2 ar}{\left(\frac{1000}{n}\right)^2}},$$

or
$$\left(\frac{1}{1-S}\frac{E}{s}\right)a^2r^2n^3 \propto N-n\mp\underline{N}, \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

where $1-S$ is the length of cord prepared with one meter of yarns. $\left(\frac{1}{1-S}\frac{E}{s}\right)$ must be supposed to depend upon the following quantities, namely : the radius of yarn, ρ, the resulting twist of yarn, $N_0{}^*\mp(N-n)$, the radius of thread, r, the resulting twist of thread, $N-n$, and the upper twist, n; then in general we may put

$$\frac{1}{1-S}\frac{E}{s} \propto \left(\frac{N_0}{N-n}\mp 1\right)^x\left(\frac{n}{N-n}\right)^y(rn)^z\left(\frac{r}{\rho}\right)^t \ldots\ldots\ldots(3)$$

The relation between n and $N-n\mp\underline{N}$ calculated with N and n in Table I as well as $\underline{N}$ in Table IV is graphically shown in Figs. 4–9. For the cords having the left-handed upper twist, the relation is represented by the following formula as seen in Figs. 4–6, notwithstanding the cord (cotton or ramie) is 2- or 3-ply

$$N-n-\underline{N}=Cn^2$$

And the value of C got from these graphs are given in Table V. Then in the case of the left-handed upper twist, $z=-1$, $t=-1$, $x=y=0$, as known from the equations (2) and (3). Accordingly $C=ca^2\rho$, c being a constant depending upon the kind of fibre only. But as seen in Table V the value

Table V.

	C	a	ρ	$\frac{C}{a^2\rho}$
3-ply cotton	0.0132	$\frac{2}{\sqrt{3}}$	0.11	0.090
2-ply cotton	0.0090	1	0.11	0.082
2-ply ramie	0.030	1	0.33	0.090

of c is the same in cotton and ramie, and it is equal to 0.087. Hence the relation between the upper and lower twists in equilibrium is expressed by

$$N-n-\underline{N}=0.087a^2\rho n^2$$

* N_0 represents the number of original twist of yarn.

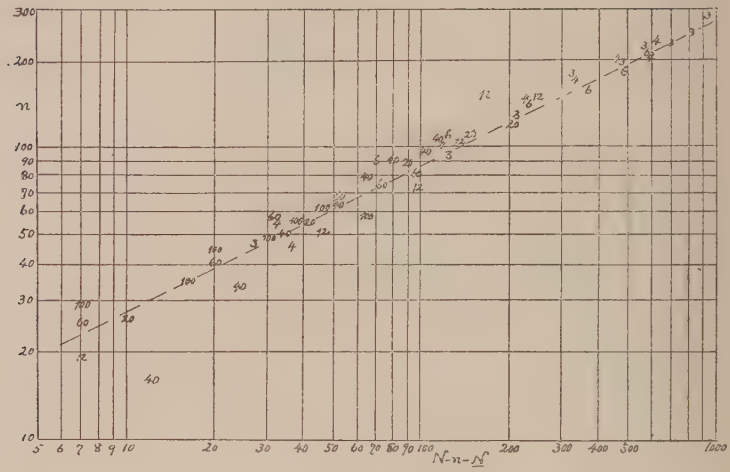

Fig. 4*.

3-ply *left* cotton cord.

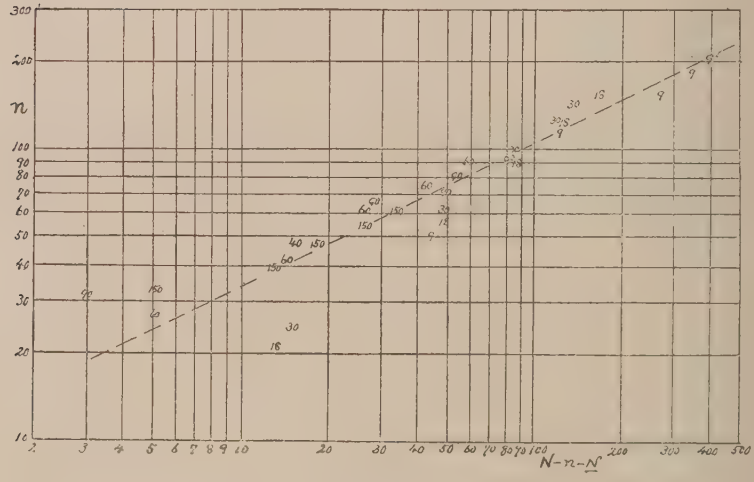

Fig. 5.

2-ply *left* cotton cord.

* Numerals in Figs. 4–9 represent the number of yarns composing each thread of cord *i.e.* the value of ν.

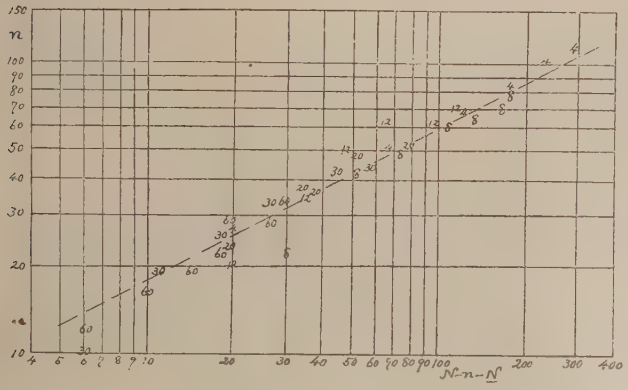

Fig. 6.

2-ply *left* ramie cord.

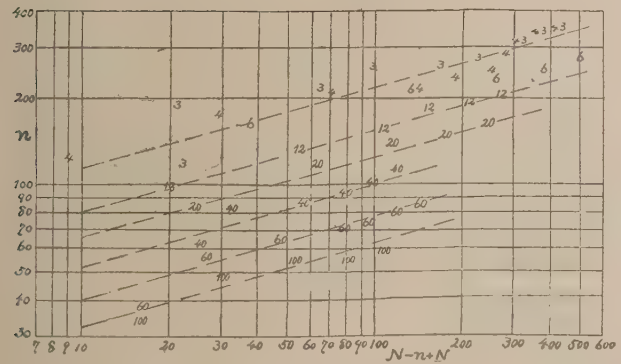

Fig. 7.

3-ply *right* cotton cord.

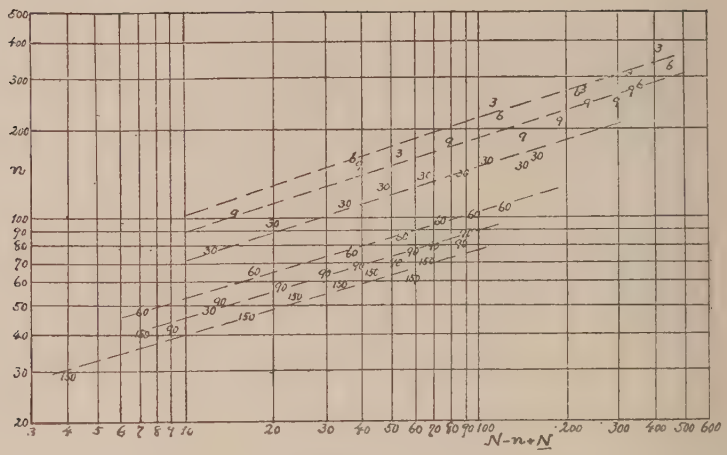

Fig. 8.

2-ply *right* cotton cord.

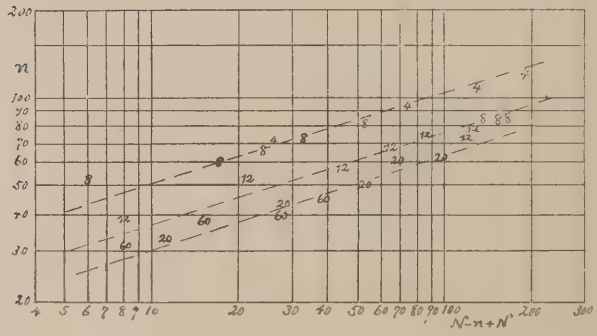

Fig. 9.

2-ply *right* ramie cord.

For the right-handed upper twist, Figs. 7–9 show that the equilibrium condition of twists is formulated as follows :—

$$N-n+\underline{N} = C'n^3$$

And the value of C' related to ν are given in Table VI and Fig. 10. Fig. 10 shows

$$C' = c'\nu$$

The value of c' got from this figure are given in Table VII. Then, in the case of the right-handed upper twist, $x=y=z=t=0$, from the equations (2)

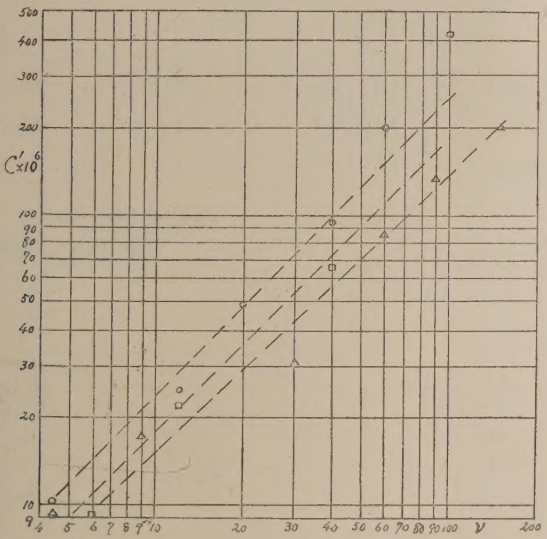

Fig. 10.

○... 3-ply *right* cotton, △... 2-ply *right* cotton,
□... 2-ply *right* ramie.

and (3). Accordingly $c'=c''a^2$, where c'' is a constant depending upon the kind of fibre only. But, as seen in Table VII, the value of c'' is the same, *ca* 1.7×10^{-6}, for cotton and ramie. Hence for the cord having the right-handed upper twist, the equilibrium condition of the twists is expressed by

$$N-n+\underline{N}=1.7\times10^{-6}a^2\nu n^3$$

TABLE VI.

3-ply cotton	ν	3—6	12	20	40	60	100
	$C'\times10^6$	10.4	25	49	94	200	420
2-ply cotton	ν	3—6	9	30	60	90	150
	$C'\times10^6$	9.6	17.3	31	86	133	200
2-ply ramie	ν	4—8	12	20—60			
	$C'\times10^6$	9.5	22	67			

TABLE VII.

	c'	a	$\frac{c'}{a^2}$
3-ply cotton	2.4×10^{-6}	$\frac{2}{\sqrt{3}}$	1.8×10^{-6}
2-ply cotton	1.6×10^{-6}	1	1.6×10^{-6}
2-ply ramie	1.8×10^{-6}	1	1.8×10^{-6}

Sept., 1929.

Physical Laboratory,
Imp. Fisher. Institute, Tôkyô.

Table I.

ν: Number of yarns composing each thread of cord, N: Number of the lower twist in 1 meter of yarn, n: Number of the upper twist in 1 meter of yarn, W: Breaking strength of cord, $2r$: Diameter of each th

3-ply *left* cotton cord.

ν	N	n	$1-S$	$W_{kg.}$	$2r_{mm.}$	$r'_{mm.}$	$\frac{2\pi r'}{\left(\frac{1000}{N-n}\right)}$	$r'(N-n)^2 \times 10^{-6}$	$\frac{p\nu\cos\alpha}{W}$
3	143	48	1.00	2.31	.46	.12	.07	.11×10⁻²	3.9
	285	94	1.00	2.81	.43		.15	.43	3.2
	430	156	1.00	3.02	.40		.21	.90	2.9
	571	176	1.00	3.32	.36		.30	1.86	2.6
	716	192	1.00	3.79	.34		.40	3.3	2.2
	858	213	.98	3.71	.33		.49	5.0	2.1
	1000	228	.94	3.65	.34		.59	7.1	2.0
	1140	245	.93	3.47	.32		.64	9.6	2.0
	1285	277	.89	3.03	.30		.76		
4	143	46	1.00	3.69	.50	.16	.10	.15	3.2
	285	104	1.00	4.59	.46		.18	.52	2.6
	430	146	1.00	5.03	.42		.28	1.28	2.3
	572	174	1.00	5.25	.41		.30	2.5	2.2
	716	194	.96	5.45	.39		.52	4.3	1.9
	858	205	.94	5.16	.38		.65	6.8	1.9
	1000	232	.90	5.21	.37		.77		
6	72	18	1.00	5.34	.67	.22	.07	.06	3.4
	143	57	1.00	6.57	.65		.12	.16	2.7
	214	90	1.00	7.38	.61		.17	.34	2.4
	285	109	1.00	7.48	.59		.24	.68	2.3
	428	141	1.00	7.94	.52		.40	1.80	2.1
	571	153	.96	7.95	.51		.57	2.2	1.9
	716	179	.91	7.59	.49		.74		
	825	202	.88	7.38	.48		.86		
12	72	19	1.00	10.68	.88	.34	.11	.10	2.3
	143	51	1.00	13.55	.85		.20	.29	2.6
	215	72	1.00	14.28	.79		.31	.70	2.4
	285	105	.97	14.41	.75		.39	1.10	2.3
	358	151	.95	14.99	.73		.44	1.46	2.2
	430	145	.91	14.45	.72		.60	2.8	2.0
20	143	56	1.00	23.71	1.02	.45	.25	.34	2.5
	285	109	.94	25.93	.95		.50	1.39	2.0
	358	120	.89	23.98	.92		.67	2.5	1.9
	214	90	.97	25.32	.99		.35	.69	2.2
	72	26	1.00	20.95	1.09		.13	.09	2.8
40	57	16	.99	39.36	1.63	.66	.17	.11	3.0
	86	33	.99	46.21	1.55		.22	.19	2.6
	114	51	.97	46.36	1.48		.26	.26	2.6
	143	63	.95	46.58	1.44		.33	.42	2.5
	172	80	.92	48.95	1.42		.38	.56	2.3
	200	91	.89	47.45	1.37		.44	.79	2.3
	228	98	.86	45.92	1.34		.53	1.11	2.2
	257	105	.84	44.78	1.34		.62	1.52	2.1
60	29	4	.99	47.02	2.01	.82	.13	.05	3.8
	57	25	.99	55.67	1.90		.17	.08	3.2
	86	41	.96	60.21	1.85		.23	.17	2.9
	114	58	.93	63.75	1.81		.29	.26	2.6
	143	67	.89	65.15	1.74		.39	.47	2.5
	172	75	.85	57.06	1.69		.50	.77	2.7
	200	80	.82	57.94	1.66		.62	1.17	2.4
100	29	8	.99	92.71	2.56	1.10	.14	.05	3.2
	43	20	.97	94.99	2.54		.16	.06	3.1
	57	29	.95	102.67	2.48		.19	.09	2.9
	72	35	.93	106.84	2.46		.25	.15	2.7
	86	45	.91	111.06	2.42		.28	.19	2.6
	100	49	.88	105.06	2.34		.35	.29	2.7
	114	56	.86	111.37	2.31		.40	.37	2.5
	128	61	.84	105.09	2.26		.46	.50	2.6
	143	58	.81	101.56	2.21		.58	.80	2.4

3-ply *right* cotton cord.

ν	N	n	$1-S$	$W_{kg.}$	$2r_{mm.}$	$r'_{mm.}$	$\frac{2\pi r'}{\left(\frac{1000}{N-n}\right)}$	$r'(N-n)^2 \times 10^{-6}$	$\frac{p\nu\cos\alpha}{W}$
3	72	118	1.00	2.84	.45				
	143	190	1.00	3.06	.44				
	214	218	1.00	3.18	.41				
	285	255	1.00	3.52	.40				
	358	260	.99	3.61	.38	.14	.09	.14×10⁻²	2.5
	430	275	.97	3.72	.38		.14	.33	2.4
	500	285	.96	3.78	.37		.19	.65	2.3
	571	320	.95	3.84	.36		.22	.89	2.3
	644	343	.94	3.78	.35		.26	1.26	2.3
	716	350	.92	3.78	.33		.32	1.88	2.3
4	72	125	1.00	4.59	.47				
	143	176	1.00	4.93	.46				
	214	206	.99	4.98	.44				
	285	216	.98	5.49	.45	.17	.07	.08	2.2
	358	234	.97	5.57	.43		.13	.26	2.1
	430	247	.94	5.86	.43		.20	.57	2.0
	500	283	.96	5.92	.41		.23	.80	2.0
	571	300	.92	6.00	.40		.29	1.25	1.9
	644	297	.90	5.85	.41		.37	2.1	1.9
	716	300	.89	5.01	.40		.45	3.0	1.8
6	143	160	.99	7.99	.57				
	285	208	.96	8.67	.53	.22	.11	.13	2.0
	430	230	.93	8.47	.50		.28	.88	2.0
	571	250	.90	8.49	.48		.44	2.3	1.9
	716	275	.84	7.56	.48		.61	4.3	1.9
12	72	98	.99	16.24	.84				
	143	134	.97	17.39	.79				
	214	154	.95	17.95	.78	.32	.12	.12	2.0
	285	181	.92	18.25	.70		.21	.35	1.9
	358	195	.90	18.06	.70		.33	.82	1.9
	430	205	.89	17.73	.66		.45	1.62	1.8
20	72	84	.98	26.32	1.08				
	143	118	.96	28.33	1.02				
	215	139	.94	27.97	1.00	.44	.21	.26	2.1
	285	148	.91	29.58	.90		.38	.83	1.9
	358	161	.86	27.92	.90		.54	1.70	1.8
40	57	61	.97	45.30	1.51				
	86	88	.95	47.56	1.51				
	114	87	.94	46.13	1.49				
	143	93	.92	46.58	1.45	.67	.21	.17	2.5
	171	102	.90	47.68	1.41		.29	.32	2.4
	200	113	.88	46.45	1.36		.36	.50	2.4
60	29	38	.97	58.19	2.01				
	57	56	.95	62.77	1.96				
	86	64	.93	59.01	1.92				
	114	70	.91	60.55	1.84	.84	.23	.16	2.9
	143	74	.89	63.44	1.83		.36	.40	2.6
	171	79	.86	61.29	1.76		.49	.71	2.6
	200	84	.82	63.62	1.70		.62	1.13	2.2
100	29	34	.96	90.00	2.61				
	57	48	.92	90.60	2.57				
	86	55	.90	95.01	2.51	1.15	.22	.11	3.1
	114	55	.86	98.24	2.42		.43	.40	2.7
	143	58	.81	91.38	2.33		.61	.83	2.6

2-ply *left* cotton cord.

ν	N	n	$1-S$	$W_{kg.}$	$2r_{mm.}$	$r'_{mm.}$	$\frac{2\pi r'}{\left(\frac{1000}{N-n}\right)}$	$r'(N-n)^2 \times 10^{-6}$	$\frac{p\nu\cos\alpha}{W}$
9	143	51	1.00	5.77	.77	.28	.17	.24×10⁻²	3.1
	285	115	.99	6.99	.64		.30	.81	2.4
	430	153	.98	7.08	.60		.49	2.15	2.2
	571	181	.95	6.96	.59		.69	4.25	1.9
	643	204	.90	6.21	.60		.92		
18	72	21	1.00	13.47	1.15	.44	.14	.11	2.7
	143	57	1.00	14.09	1.00		.24	.32	2.5
	214	91	1.00	15.27	.97		.37	.67	2.2
	285	126	.95	15.11	.94		.44	1.11	2.1
	357	154	.92	13.90	.91		.56	1.81	2.3
30	72	25	1.00	21.35	1.39	.54	.16	.12	2.8
	143	63	.99	24.93	1.26		.27	.35	2.3
	214	100	.95	25.40	1.18		.38	.71	2.2
	285	128	.92	24.55	1.13		.53	1.33	2.1
	313	147	.89	22.27	1.10		.56	1.49	2.2
60	57	27	.99	42.48	1.95	.84	.16	.08	2.8
	86	42	.97	43.91	1.85		.23	.16	2.6
	114	63	.95	44.82	1.82		.27	.22	2.6
	143	76	.93	44.16	1.76		.35	.38	2.5
	172	90	.90	44.09	1.68		.43	.57	2.4
	200	93	.87	41.81	1.69		.56	.97	2.4
90	29	12	.99	55.99	2.58	1.05	.11	.03	3.2
	57	32	.97	62.37	2.44		.16	.07	2.8
	86	49	.94	65.98	2.34		.24	.14	2.6
	114	64	.91	63.70	2.25		.33	.26	2.7
	143	71	.87	62.33	2.17		.47	.54	2.5
	157	81	.85	58.93	2.13		.50	.61	2.6
150	29	12	.98	97.48	3.50	1.43	.15	.04	3.0
	43	23	.96	99.69	3.34		.18	.06	3.0
	57	33	.94	101.74	3.27		.22	.08	2.9
	72	40	.92	101.50	3.15		.29	.15	2.9
	86	49	.90	107.83	3.08		.33	.20	2.6
	100	55	.86	98.78	2.96		.40	.29	2.8
	114	61	.83	94.34	2.87		.48	.40	2.8

2-ply *right* cotton cord.

ν	N	n	$1-S$	$W_{kg.}$	$2r_{mm.}$	$r'_{mm.}$	$\frac{2\pi r'}{\left(\frac{1000}{N-n}\right)}$	$r'(N-n)^2 \times 10^{-6}$	$\frac{p\nu\cos\alpha}{W}$
3	143	166	1.00	1.30	.44				
	285	241	1.01	1.34	.39				
	430	273	.99	1.56	.37	.14	.14	.34×	
	571	313	.97	1.63	.36		.23	.93	
	716	378	.93	1.48	.33		.30	1.60	
6	143	160	1.00	4.06	.58				
	285	220	.97	4.36	.54	.23	.09	.01	
	430	266	.94	4.57	.51		.24	.62	
	571	277	.92	4.48	.50		.42	1.98	
	716	322	.86	4.12	.50		.57	3.6	
9	72	104	1.00	5.71	.71				
	143	151	.99	6.62	.69				
	214	181	.98	6.81	.66				
	285	188	.96	7.08	.64	.28	.17	.26	
	358	213	.94	7.51	.63		.26	.59	
	430	241	.93	7.78	.61		.33	1.00	
	500	247	.90	6.75	.60		.45	1.80	
	571	275	.89	6.70	.59		.52	2.5	
18	72	98	.99	11.98	1.04				
	143	137	.98	13.02	.97				
	214	155	.96	13.75	.92	.42	.15	.14	
	285	173	.94	14.49	.89		.29	.53	
	358	194	.91	14.95	.86		.43	1.13	
30	29	49	.99	19.42	1.49				
	57	77	.98	20.97	1.38				
	86	98	.97	21.98	1.35				
	114	111	.96	22.77	1.30				
	143	127	.95	22.39	1.26				
	172	139	.95	22.91	1.25	.56	.12	.06	
	200	143	.93	22.91	1.22		.20	.18	
	228	153	.92	23.51	1.19		.26	.31	
	257	150	.90	23.09	1.15		.39	.64	
	285	160	.88	22.83	1.14		.44	.88	
60	29	47	.98	37.02	2.08				
	57	65	.98	41.53	2.00				
	86	75	.94	41.25	1.95				
	114	86	.94	39.97	1.95	.88	.15	.07	
	143	96	.91	42.54	1.82		.26	.20	
	172	101	.88	43.19	1.78		.39	.44	
	200	107	.84	42.94	1.75		.51	.76	
90	29	42	.97	49.25	2.80				
	43	52	.95	52.05	2.60				
	57	58	.95	55.61	2.59				
	72	64	.92	53.03	2.53				
	86	69	.92	52.22	2.48	1.11	.12	.03	
	100	70	.90	53.00	2.43		.21	.10	
	114	77	.90	54.27	2.39		.26	.15	
	128	80	.88	57.07	2.36		.34	.25	
	143	81	.86	55.69	2.29		.43	.42	
	157	89	.84	55.69	2.24		.47	.51	
150	14	29	.97	75.55	3.90				
	29	41	.95	81.66	3.57				
	43	46	.93	80.25	3.45				
	57	53	.92	81.65	3.37				
	72	58	.90	82.75	3.30				
	86	63	.88	84.93	3.22	1.48	.21	.08	
	100	61	.86	86.88	3.11		.36	.22	
	114	70	.85	86.46	2.96		.41	.29	

read of cord, r': Radius of simple helix constructed by each yarn of thread.

		2-ply *left* ramie cord.										2-ply *right* ramie cord.									
	$\frac{pv\cos\alpha}{W}$	v	N	n	$1-S$	$W_{kg.}$	$2r_{mm.}$	$r'_{mm.}$	$\frac{2\pi r'}{\left(\frac{1000}{N-n}\right)}$	$r'(N-n)^2\times10^{-6}$	$\frac{pv\cos\alpha}{W}$	v	N	n	$1-S$	$W_{kg.}$	$2r_{mm.}$	$r'_{mm.}$	$\frac{2\pi r'}{\left(\frac{1000}{N-n}\right)}$	$r'(N-n)^2\times10^{-6}$	$\frac{pv\cos\alpha}{W}$
		4	72	27	1.00	11.03	1.39	.44	.12	$.09\times10^{-2}$	.73	4	72	71	1.00	15.02	1.12				
			143	51	1.01	16.05	1.26		.25	.37	.48		143	94	.97	17.56	1.04				
	3.8		214	69	.99	16.96	1.14		.40	.92	.43		214	110	.94	19.38	1.02	.43	.28	$.46\times10^{-2}$	.40
	3.5		285	85	.97	16.87	1.13		.55	1.75	.40		285	121	.89	18.91	1.00		.44	1.15	.38
	3.8		357	103	.95	16.72	1.04		.70	2.8	.35	8	29	43	.99	29.27	1.77				
			428	115	.90	15.28	1.03		.86				57	60	.98	30.11	1.69				
	2.7	8	43	9	1.00	23.76	1.89	.70	.15	.07	.68		72	68	.98	31.94	1.68				
	2.5		72	22	1.00	30.17	1.75		.22	.18	.52		86	73	.96	30.74	1.66				
	2.4		114	42	.98	34.38	1.74		.32	.36	.44		114	81	.95	30.17	1.58				
	2.4		143	49	.96	35.55	1.66		.41	.62	.41		143	84	.93	35.33	1.56	.71	.27	.25	.43
			186	60	.93	36.60	1.65		.55	1.11	.37		172	84	.90	33.61	1.52		.40	.55	.44
			214	62	.92	35.38	1.61		.67	1.61	.33		200	85	.87	32.98	1.48		.52	.94	.41
			257	70	.87	32.23	1.60		.82				214	83	.84	36.47	1.49		.59	1.22	.35
	2.5		285	78	.84	28.71	1.49		.91				229	85	.82	30.22	1.52		.64	1.47	.40
	2.3	12	29	5	1.00	35.58	2.49	.93	.14	.05	.67	12	29	38	.98	40.66	2.31				
	2.2		57	20	.99	43.57	2.37		.22	.13	.54		57	53	.97	45.07	2.19				
	2.4		86	34	.97	49.13	2.23		.30	.25	.46		86	58	.95	47.03	2.10				
	2.3		114	50	.94	51.70	2.18		.37	.38	.43		114	68	.92	48.84	2.02	.90	.26	.19	.48
			143	62	.93	51.20	2.09		.47	.60	.41		143	75	.88	50.18	1.90		.38	.42	.44
			172	61	.89	48.91	2.05		.65	1.15	.37		172	72	.85	49.94	1.85		.56	.90	.40
	2.6		200	70	.86	45.37	1.94		.76	1.56	.35		186	79	.82	49.86	1.88		.60	1.03	.39
	2.4	20	29	5	1.00	63.87	3.17	1.25	.19	.07	.61	20	29	33	.97	60.29	3.21				
	2.2		57	23	.97	78.87	2.96		.27	.14	.49		57	44	.95	67.08	2.94				
			86	37	.94	82.20	2.87		.39	.30	.45		86	50	.91	79.14	2.77	1.23	.28	.16	.48
			114	48	.90	78.60	2.70		.52	.54	.43		114	61	.91	84.53	2.62		.41	.34	.43
			143	52	.85	75.78	2.56		.72	1.04	.37		143	62	.82	76.69	2.46		.63	.81	.40
		30	14	2	1.00	74.03	4.09	1.57	.12	.02	.81	30	14	26	.99	83.27	4.29				
			29	10	.99	92.99	3.94		.19	.06	.63		29	36	.96	92.44	4.11				
	2.6		43	19	.97	103.99	3.79		.24	.09	.56		43	46	.92	97.08	3.74				
	2.6		57	26	.94	109.56	3.68		.31	.15	.52		57	51	.90	94.67	3.65				
	2.5		72	33	.92	109.16	3.51		.38	.24	.51		72	53	.89	93.79	3.42				
	2.4		86	37	.91	105.58	3.39		.48	.38	.50		86	52	.86	102.80	3.35	1.51	.32	.17	.55
	2.4		100	43	.86	103.03	3.35		.56	.51	.48		100	53	.83	105.53	3.23		.45	.33	.50
			114	44	.81	93.35	3.20		.69	.77	.46		114	56	.79	102.34	3.08		.55	.41	.49
		60	14	3	.99	151.80	5.79	2.39	.16	.03	.78	60	14	24	.95	123.90	5.81				
			21	8	.97	154.32	5.71		.20	.04	.76		29	31	.92	142.01	5.62				
	3.0		29	12	.95	174.33	5.66		.26	.07	.66		43	38	.89	144.65	5.31				
	2.7		36	16	.93	166.00	5.66		.30	.10	.68		57	40	.86	153.48	5.14				
	2.6		43	19	.92	181.05	5.44		.36	.14	.62		72	45	.83	150.16	4.71	2.33	.40	.17	.72
	2.4		50	22	.90	179.41	5.25		.42	.19	.60	100	7	16	.96	172.71	8.27				
			57	28	.87	182.45	5.14		.44	.20	.59		14	21	.94	200.87	7.78				
			64	28	.85	177.78	4.98		.54	.31	.56		21	25	.91	192.52	7.37				
			72	33	.83	172.33	4.81		.59	.36	.56		29	27	.90	216.80	7.30				
													36	29	.89	201.02	7.02				
	3.4												43	28	.85	210.14	6.79	3.25	.31	.07	.90
	3.3												50	30	.82	212.88	6.52		.41	.13	.85
	3.2																				
	3.0																				
	2.8																				
	2.8																				
	3.4																				
	3.2																				
	3.2																				